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On the Study of Setting Dynamics of Axial Piston Pumps with Electro Hydraulic Proportional Control

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Abstract

The paper considers recent trends in the development of electrically operated hydraulic drive. The main requirements to the dynamic characteristics of variable axial piston pumps with electric control and the need for search of ways of their improvement are specified. The investigation results show the dynamic characteristics of the process to control electro-hydraulic axial piston pump capacity at different parameters of pulse width modulation (PWM) signal. The regularity between PWM-signal frequency and the time of establishing the proper pump displacement was found. The paper stresses the need for more detailed study of this fact and its usage for the optimization of variable pump regulation speed in order to be applied in electro-hydraulic flow control systems.

Keywords: axial piston pump; proportional electro-hydraulic control; pulse width modulation (PWM); linearization by oscillation; dithering.

1. Introduction

The enhancement of dynamic characteristics, energy efficiency, performance and operating comfort are the main trends of the hydraulic drive systems development. Using hydraulic drive with electric control allows to realize the most effective and flexible drive systems of processing machinery and to facilitate the work of operators.

The flow control operating principle of working hydraulic drives is actively developing. This operating principle being more energy efficient is based on using axial piston pump with proportional electric control.

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To increase the efficiency of flow control systems as compared to that of conventional pressure control systems (load sensing) became possible due to the reduction of losses across the directional valve. The pump displacement is consistent with the electric control signal, thus the directional valve is fully open resulting in minimum resistance.

Mentioned above control type has different names: “Electro-hydraulic flow matching” (EFM), “Electro-hydraulic Load Sensing” (ELS), “Flow-on-demand system”, etc. [1-5]

However, pumps with electro-hydraulic controllers are frequently inferior to their counterparts with hydro-mechanical controllers in terms of dynamic characteristics [6]. Thus, this influences the system functionality when the pump capacity is to change fast enough for the synchronization of the produced volume flow rate with the demanded one. Consequently, it necessitates the search for methods to improve the axial piston pump setting dynamic.

Nomenclature

A	the cavity of smaller diameter of the pump controller
B	the cavity of larger diameter of the pump controller
P	pressure in the cavity B
S	position of the pump controller piston
T	the settling time of the required position of the pump controller piston
f_{PWM}	frequency of the control signal with pulse width modulation

2. Statement of the problem

The object of the study is the variable axial piston pump with proportional electric control produced by “PSM-Hydraulics”. The pump has bent-axis design.

There are two studies related to the investigation and modelling of the electro-hydraulic controller of the mentioned hydraulic machines [6, 7]. The following problems associated with operation modes of directional spool valve and its simulation were determined by the authors:

- high spool friction;
- inaccuracy of mathematical model of the throttled fluid flow.

The pulse-width modulated (PWM) electric signal is used for controlling the electro hydraulic pump controller. The oscillation of the current in the solenoid valve coil causes the oscillation of the spool. It has essential influence on the valve flow conductance, reduces spool friction and increases responsivity of the pump controller [8-10]. The actuator of the pump controller is also exposed to frequency alternating loads caused by the impact of pressure pulsations in its cylinder. It decreases friction in all elements of the pump controller and changes system dynamics [11, 12]. This effect is referred to as the dithering [13-16] or the linearization by oscillation [17, 18].

The knowledge about PWM-signal influences on different parameters allows to optimize the pump setting velocity as well as to decrease friction, to increase responsivity and accuracy of the pump controller.

3. Preparation of the experiment

The paper presents the results of experimental investigation. The aim was to determine the relationship between the variable axial piston pump setting dynamics and the parameters of the pump controller spool oscillation, which is related to the PWM of the control signal. The electro-hydraulic pump controller is presented in Fig. 1.

The displacement of the pump depends on the cylinder block angle relative to the pump shaft axis. It is controlled by the electro-hydraulic pump controller, which is built into the back cover of the pump. The pump controller consists of differential piston 1, pin 2, directional spool valve 3, two-armed lever 4 and the proportional solenoid 5.

The cavity “A” is continuously connected with the discharge port of the pump. The cavity “B” can be connected with the inlet port or the cavity “A” through the holes in the differential piston and by means of the directional spool valve. The spool position is changed when feeding the control signal to the proportional solenoid coil, which changes torque balance on the two-armed lever.

The neutral spool position ensures the balance of forces applied to the differential piston. The movement of the spool changes the pressure in the cavity "B" and causes the piston motion [19].

Experiments were conducted on the laboratory test bench at "PSM-Hydraulics" under nominal working modes: rotation frequency – 1500 rpm; pressure in the discharge port – 200 bar. Maximal displacement is 55 cm^3, pump performance is 75 l/min. The following frequency values of the PWM-signal were chosen: 50, 100, 200, 300, 400, 500 Hz.

A step input signal was used as the test input that switches the pump displacement from minimum up to ¾ of maximum value that allows to watch overshoots of the controlled parameter.

The observed parameter is the settling time of the required position of the pump controller piston. The stroke transducer was applied for monitoring the piston motion [20]. In addition, the pressure transducer was installed in the cavity "B".

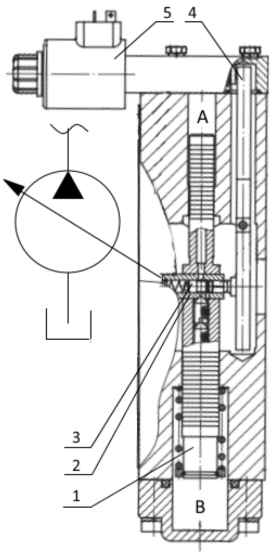

Fig. 1. The electro hydraulic pump controller (controlled pump is shown schematically).

4. Experiment results

Step response curves of the piston motion S(t) and the pressure P(t) in the cavity "B" have been obtained as a result of experiments for different frequencies of the PWM control signal f_{PWM} (see Fig. 2). Vertical lines on graphs indicate a feeding of a step input and the settling time of the required position of the pump controller piston.

As can be seen from graphs the settling time of the required pump displacement is declined with f_{PWM} rising from 50 Hz up to 300 Hz. A further increase of the PWM-signal frequency gives the opposite effect since a type of a transient response is changed. Moreover, the static mistake of the system grows with increase of the f_{PWM}.

At the f_{PWM} from 50 Hz up to 200 Hz the system is sluggish in responding. The overshoot is appeared in a system responding at the f_{PWM}=300 Hz. With the f_{PWM} more than or equal to 400 Hz, the system exhibits damped oscillations before reaching the steady state. The smallest value of settling time is obtained at f_{PWM}=300 Hz.

The settling time value and the type of a transient response depend on the PWM-signal frequency that can be explained by the change of amplitude and frequency pressure ripples in the cavity "B". As shown on the presented graphs, the pressure ripples amplitude is drastically reduced with the increase of the f_{PWM} to more than 200 Hz. It results in the valve flow conductance improvement and deliverance from pressure spikes inhibiting the piston motion.

During the experiments, the match of pressure ripples and PWM-signal frequencies is established up to 125 Hz and it is vanished at further increase of a frequency. Moreover, it is noted that spool oscillation determines the second and more higher harmonics of pressure ripples.

The change of the ripples amplitude is related to a spool valve overlap and its oscillation amplitude. As shown in [15], the solenoid valve core oscillations amplitude is decreased with a PWM-signal frequency increasing.

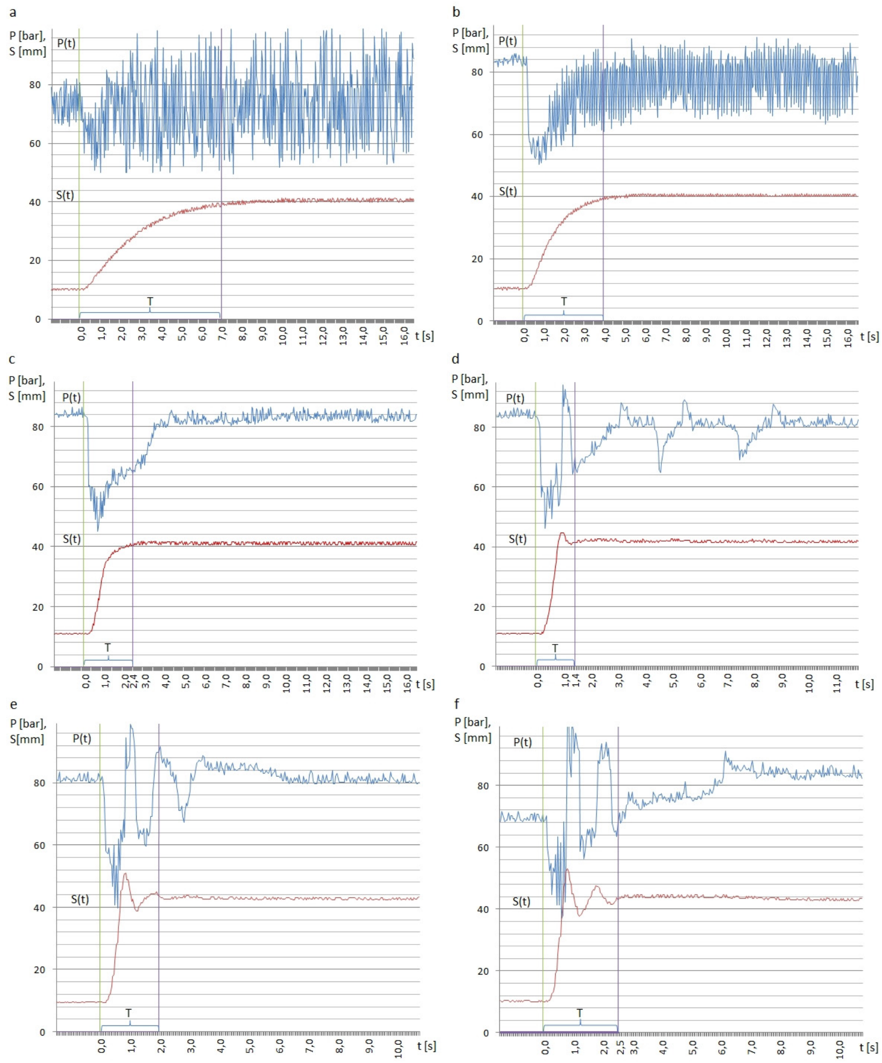

Fig. 2. Step response curves of the pressure P(t) in the cavity "B" and the piston motion S(t) at different frequencies of the PWM control signal fPWM (a) fPWM=50 Hz; (b) fPWM=100 Hz; (c) fPWM=200 Hz; (d) fPWM=300 Hz; (e) fPWM=400 Hz; (f) fPWM=500 Hz.

Moreover, in the investigated pump controller the amplitude of spool oscillations depends on the piston position, which is associated with the balance of lever arms.

Appearance of overshoots of the controlled parameter is related to the increase of the motion velocity of pump parts having inertia.

The graph of the settling time T versus different f_{PWM} is shown in Fig. 3. It is built according to experimental data.

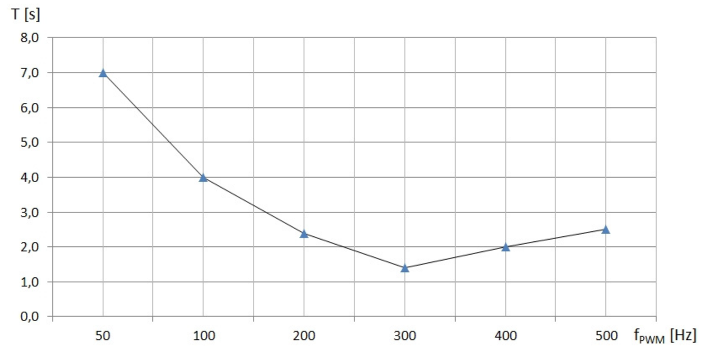

Fig. 3. Value of the settling time T vs PWM-signal frequency fPWM.

5. Conclusion

Experiment results of setting dynamics of the axil piston pump with proportional electric control at different values of the PWM-signal frequency are presented. The regularity between frequency of the PWM-signal and the settling time of the pump displacement was discovered.

It is necessary to examine in more detail the influence of the PWM control signal on electro-hydraulic controllers performance and setting process of the displacement of pumps applied in the flow control systems. It allows to choose optimal parameters of the PWM-signal and to improve pump controllers performance and its controllability.

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